

# Observations of Hydration and Dehydration in the Winter 2000 Arctic Stratosphere

**Robert L. Herman<sup>1</sup>, Katja Drdla<sup>2</sup>, Bruce W. Gandrud<sup>3</sup>, Chris R. Webster<sup>4</sup>, and T. Paul Bui<sup>5</sup>**

<sup>1</sup> Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 183-401, 4800 Oak Grove Drive, Pasadena, CA 91109, (818) 393-4720, [Robert.Herman@jpl.nasa.gov](mailto:Robert.Herman@jpl.nasa.gov)

<sup>2</sup> NASA Ames Research Center, Mail Stop 245-4, Moffett Field, CA 94035, (650) 604-5663, [katja@aerosol.arc.nasa.gov](mailto:katja@aerosol.arc.nasa.gov).

<sup>3</sup> National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307  
(303) 497-1038, [gandrud@ucar.edu](mailto:gandrud@ucar.edu).

<sup>4</sup> Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 183-401, 4800 Oak Grove Drive, Pasadena, CA 91109, (818) 354-7478, [Chris.R.Webster@jpl.nasa.gov](mailto:Chris.R.Webster@jpl.nasa.gov)

<sup>5</sup> NASA Ames Research Center, Mail Stop 245-4, Moffett Field, CA 94035, (650) 604-5534, [pbui@mail.arc.nasa.gov](mailto:pbui@mail.arc.nasa.gov).

## Abstract

During the January 2000 deployment of the SAGE III Ozone Loss Validation Experiment (SOLVE), the NASA ER-2 aircraft intercepted air parcels with unusual water mixing ratios within the Arctic polar vortex. Simultaneous *in situ* measurements of H<sub>2</sub>O by the JPL Laser Hygrometer and CH<sub>4</sub> by the Aircraft Laser Infrared Absorption Spectrometer were used to infer up to 0.5 ppm hydration (approximately 10%) at 18 km pressure-altitude (70 hPa) on January 31, 2000. Up to 0.5 ppm dehydration was inferred at a higher altitude of 20.6 km (50 hPa) on January 27, 2000, and 2 ppm dehydration at lower altitude on January 23. The thermal histories of these air masses are studied using back-trajectory analyses. The extent of observed dehydration is less than expected, given the low temperatures of the Arctic vortex during December, 1999, and January, 2000.

## Introduction

It is generally acknowledged that stratospheric chlorine is activated by heterogeneous reactions on polar stratospheric clouds (PSCs). Ozone is catalytically removed by reaction with chlorine, leading to springtime ozone reduction in the polar regions. In the Arctic lower stratosphere, temperatures during winter and spring are close to the threshold for PSC formation, leading to greater sensitivity of ozone to temperature changes [WMO, 1999]. Anthropogenic increases in greenhouse gases are predicted to cause even greater ozone loss in the future, due to the evolution of a colder, more stable Arctic polar vortex [Shindell et al., 1998] as well as increases in stratospheric water vapor concentrations [Rind et al., 1998]. Thus, the importance of understanding the chemistry and microphysics of PSCs cannot be overstated. This analysis utilizes simultaneous *in situ* measurements of water vapor and CH<sub>4</sub> mixing ratios to infer the extent of water sinks (dehydration) or sources (hydration) in the Arctic polar stratosphere.

## Measurements

In this analysis, we examine *in situ* data collected on the NASA ER-2 high-altitude research aircraft during the NASA SAGE III Ozone Loss Validation Experiment (SOLVE). The ER-2 was based in Kiruna, Sweden (67 N, 21 E) during January through March, 2000. The high latitude of this site allowed direct access to the Arctic polar vortex on nearly every ER-2 flight. Water vapor is measured *in situ* by the JPL Laser Hygrometer (JLH), a near-infrared diode laser absorption spectrometer on the ER-2 [May, 1998]. This is a high-precision instrument that records water vapor data at 0.7 Hz with typically 1% precision and 5% accuracy at the ER-2 cruise altitude of 20 km (approx. 50 hPa). Nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>) measurements are made by the Aircraft Laser Infrared Absorption Spectrometer (ALIAS) [Webster et al., 1994] with a 2-sec precision of 2% and accuracy of 3%. Temperature and pressure measurements are provided by the Meteorological Measurement System (MMS) [Scott et al., 1990]. Particle volume density measurements come from the MASP instrument [Baumgardner et al.].

## Observations

The amount of water vapor that can enter the stratosphere is limited by passage through the cold trap at the tropical tropopause [Brewer et al., 1949]. A significant stratospheric source of water is methane oxidation. Therefore, total hydrogen  $\hat{H} = 2*[\text{CH}_4] + [\text{H}_2\text{O}]$  should be conserved in the absence of additional sources or sinks of water. We have used this measured parameter to search for evidence of dehydration or hydration in the Arctic polar vortex during the SOLVE campaign. Temperatures below the frost point are occasionally seen in the winter polar stratosphere. Water condenses into polar stratospheric clouds at a few degrees K below the ice frost point [Tabazedeh et al., 2000], and the particles grow and sink, permanently removing water from that air parcel (dehydration). At lower altitudes, where the temperature is above the frost point, it is expected that these particles will evaporate (hydration). This is reflected in the total hydrogen measurements from the ER-2, as shown in Figure 1.

Total Hydrogen Inside the Polar Vortex, Jan.-Feb. 2000  
(CH<sub>4</sub>: ALIAS, H<sub>2</sub>O: JLH)

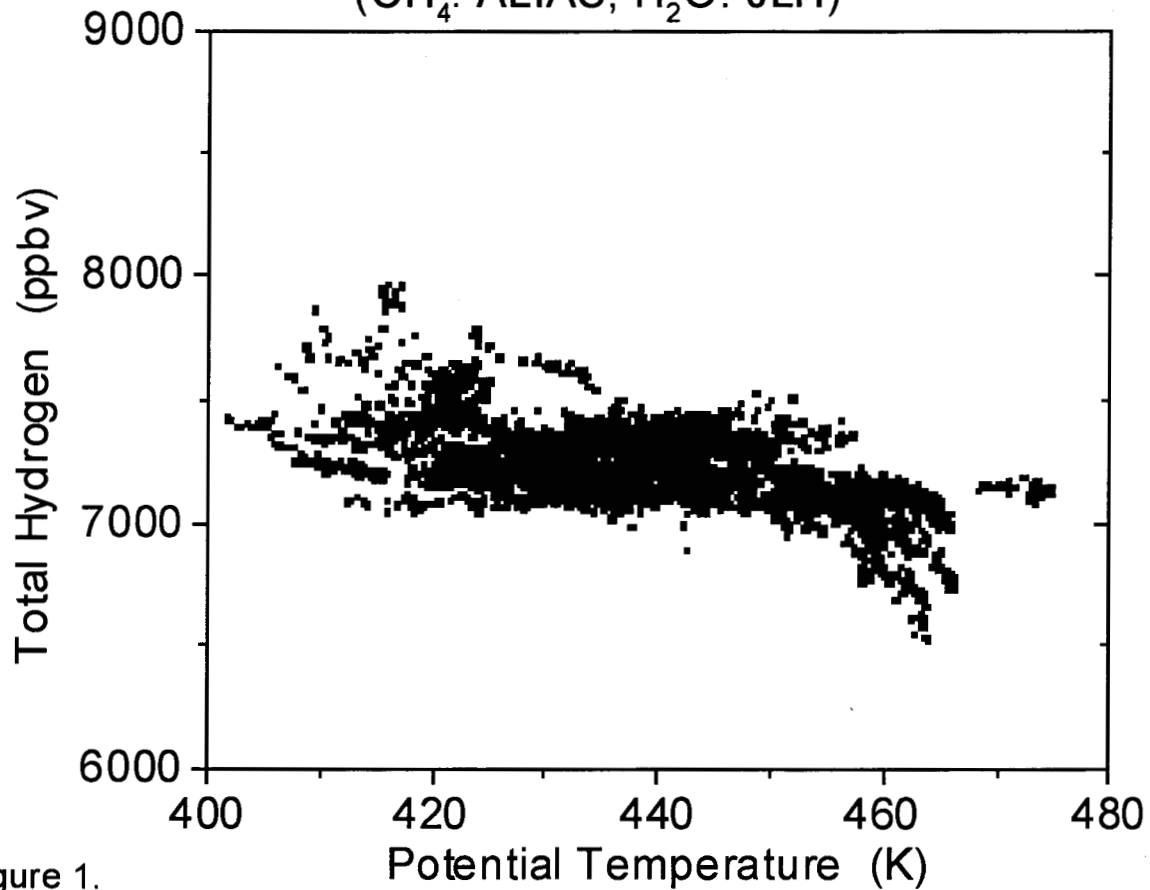
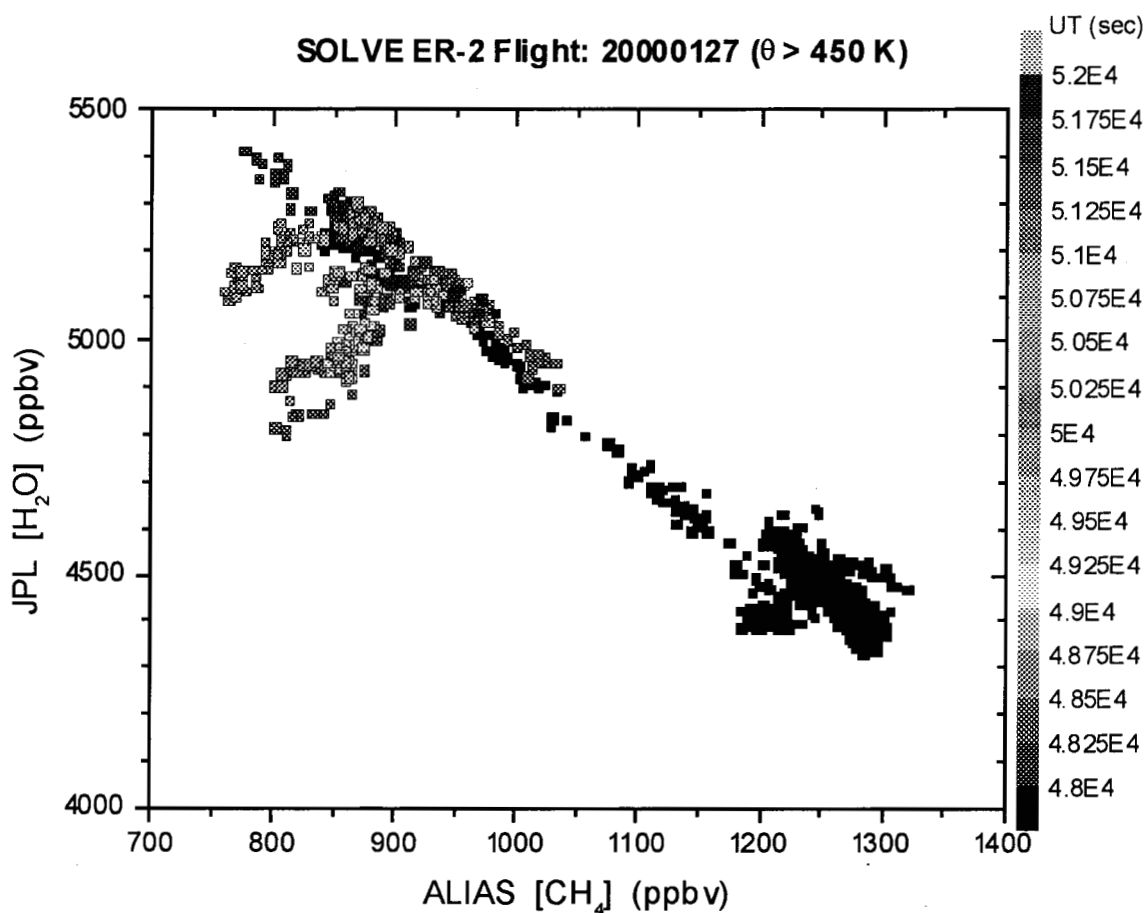


Figure 1.

Figure 1. Total hydrogen  $\hat{H} = 2*[\text{CH}_4] + [\text{H}_2\text{O}]$  measured inside the Arctic polar vortex during January and February, 2000, from the NASA ER-2 aircraft. Water measurements are from JLH and methane measurements are from ALIAS. Potential temperature  $\theta = T*(1000/p)^\kappa$ , where  $\kappa = 0.286$ . Total hydrogen is less than 7000 parts per billion by volume (ppbv) due to dehydration in an air parcel sampled on January 27, 2000, at 460 K (50 hPa). Total hydrogen is enhanced at lower potential temperatures (415 K, or approximately 70 hPa) due to hydration by evaporation of Type 2 PSCs (water ice).



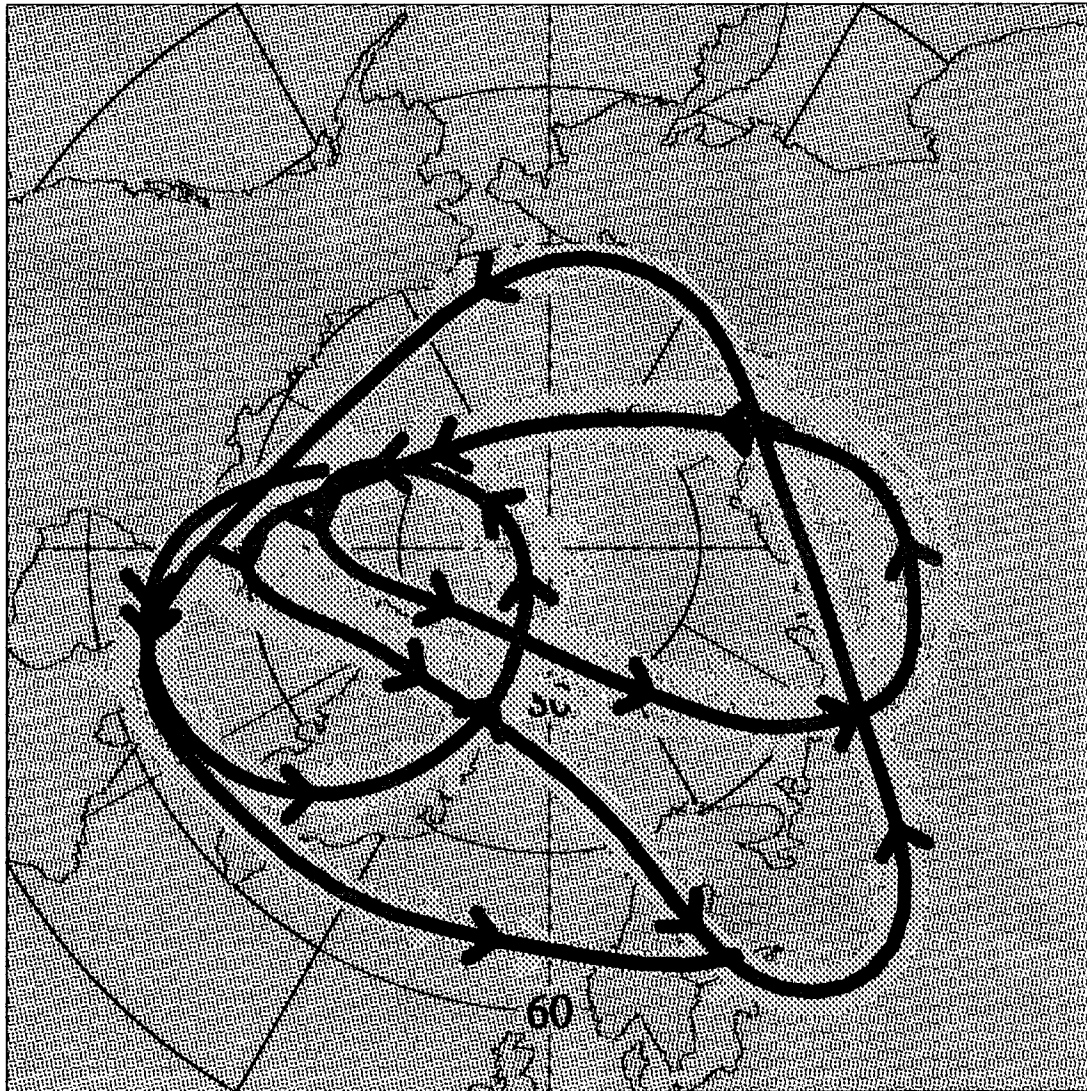
**Figure 2.**

Figure 2. The dehydrated air parcel sampled on the ER-2 flight of January 27, 2000, is evident in the H<sub>2</sub>O vs. CH<sub>4</sub> correlation. Between 48,160 and 50,200 sec UT, there is a departure from the normal inverse relationship between H<sub>2</sub>O vs. CH<sub>4</sub>. This is indicative of up to 500 ppbv dehydration (9% of the water) in this air parcel. The particle volume density is negligible during these times, so essentially all of the water is in the vapor phase. These air parcels are just inside the polar vortex, at 20.6 km altitude (50 hPa), and are the only example of significant dehydration from the *in situ* ER-2 data during SOLVE.

On the following two pages, a diabatic back-trajectory analysis [M. Schoeberl, pers. comm.] of the dehydrated air parcel suggests that it passed through the cold pool of the Arctic vortex in early January, 2000, experiencing temperatures as low as 183 K. For several days, the temperature was below the ice frost point, allowing freezing and growth of Type 2 PSCs. Sedimentation of these particles partially depleted the air parcel of water vapor.

# Trajectories for Dehydration Event

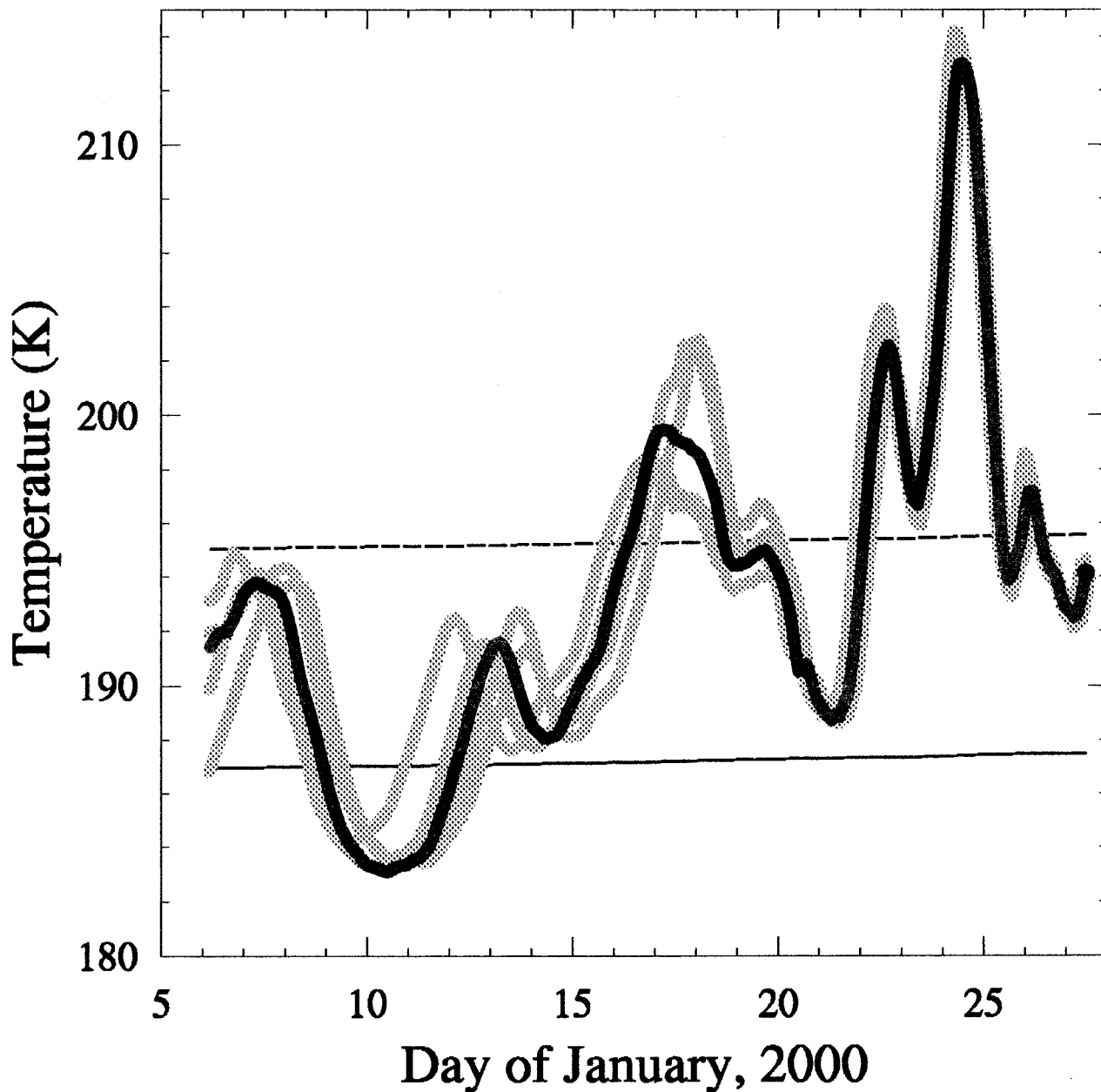
Cluster generated for Jan. 27, 2000, 48400 UT



- Measurement location
- Central trajectory
- Location of cold pool
- Other trajectories in cluster

# Trajectories for Dehydration Event

Cluster generated for Jan. 27, 2000, 48400 UT



- Measurement location
- Location of cold pool
- Central trajectory
- Other trajectories in cluster
- Ice Frost Point
- NAT Condensation Point

## Modeling

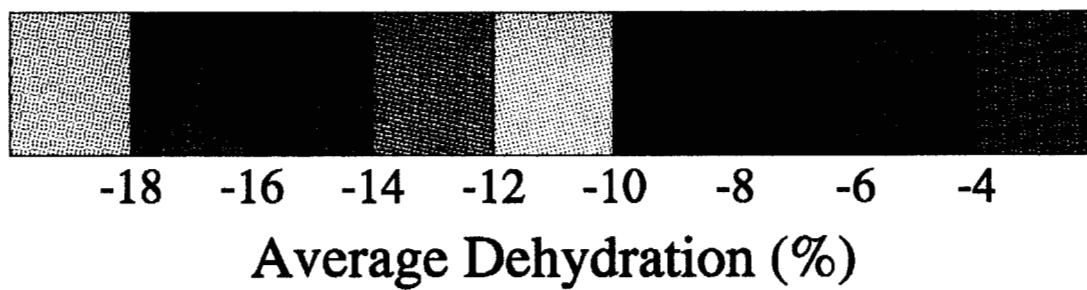
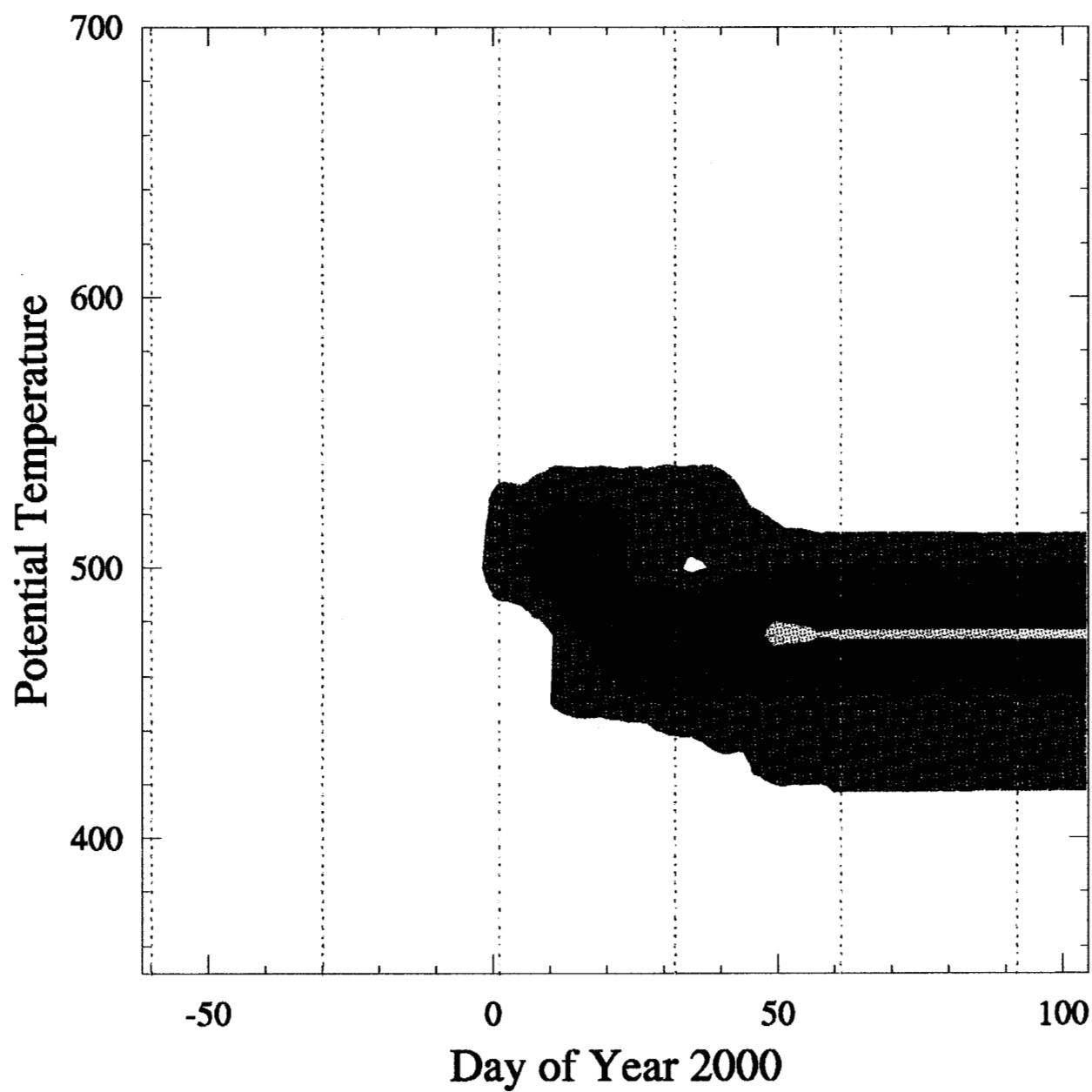
To further explore the presence of Type 2 PSCs in the 2000 winter Arctic polar vortex, we utilized the Integrated Microphysics and Aerosol Chemistry on Trajectories model (IMPACT). This model follows diabatic trajectories of more than 2000 air parcels within the Arctic polar vortex. A full particle microphysics code allows condensation, freezing, sublimation, aggregation, and sedimentation of PSCs.

Unlike the observations, the model predicts extensive dehydration of the 2000 winter Arctic polar vortex. Specifically, the model predicts mean dehydration of 8% at 460 K. In the observations, only one flight intercepted dehydrated air at 460 K, and that air parcel accounted for only a small fraction of the flight. On the next several pages are shown the model evolution of water vapor as a function of potential temperature and day of the year since January 1, 2000.

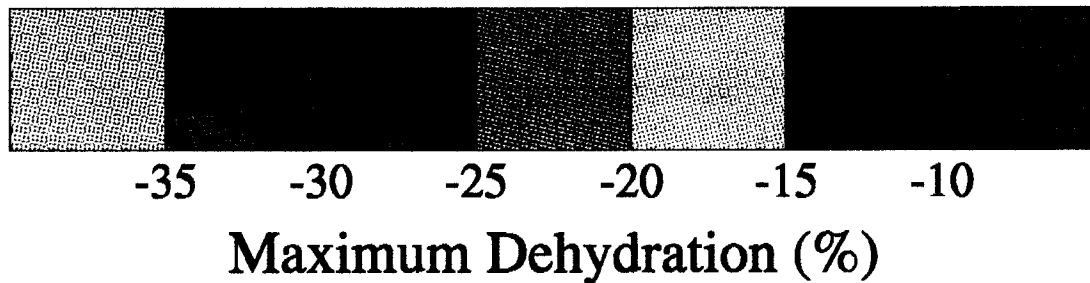
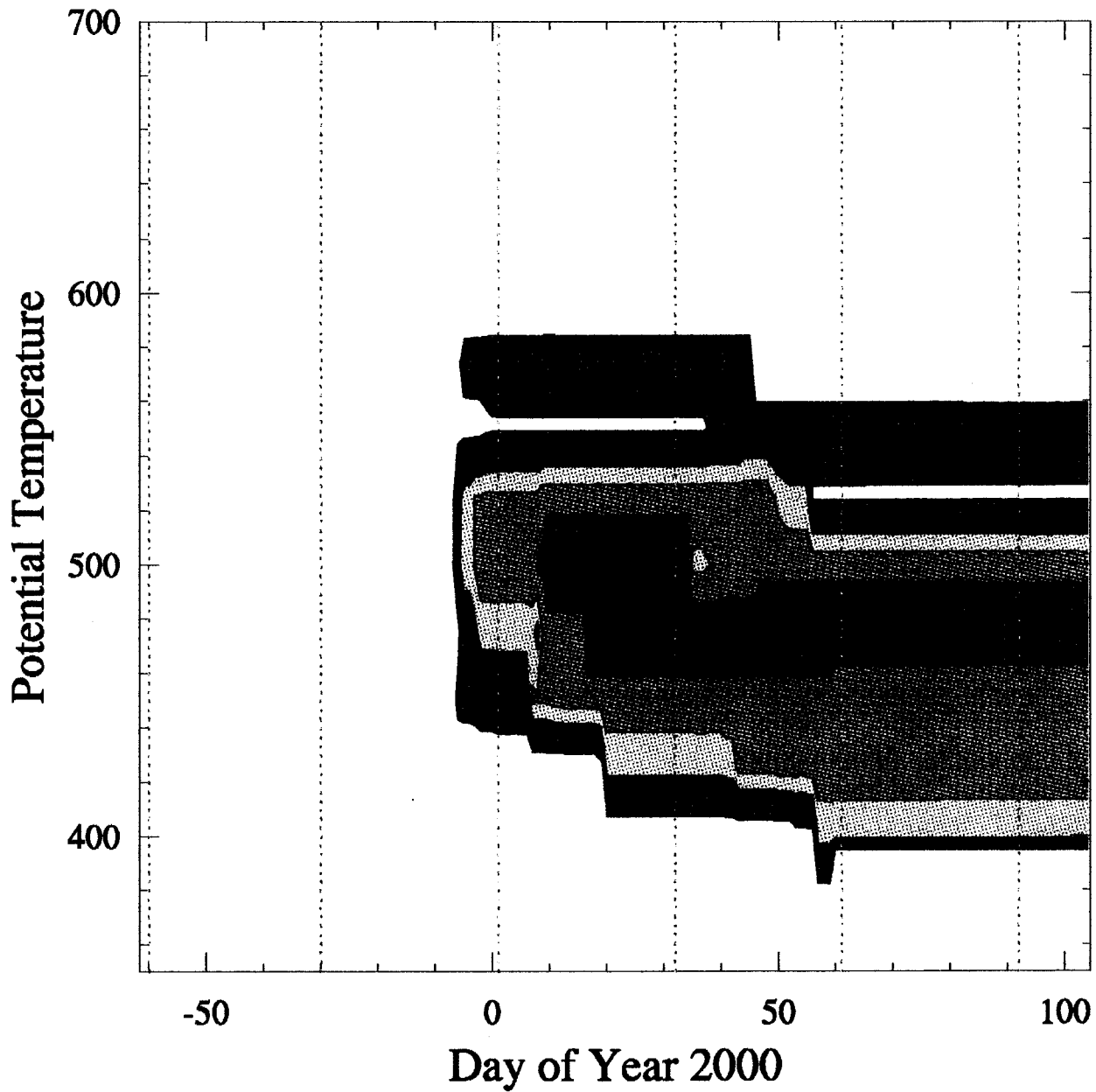
There are several possible reasons why the model overestimates dehydration in the polar vortex. The most likely reason is a systematic error in the UKMO temperatures used in the model. It is also possible that particles grow slower than in the model, preventing sedimentation, or that they freeze at lower temperatures than previously thought.



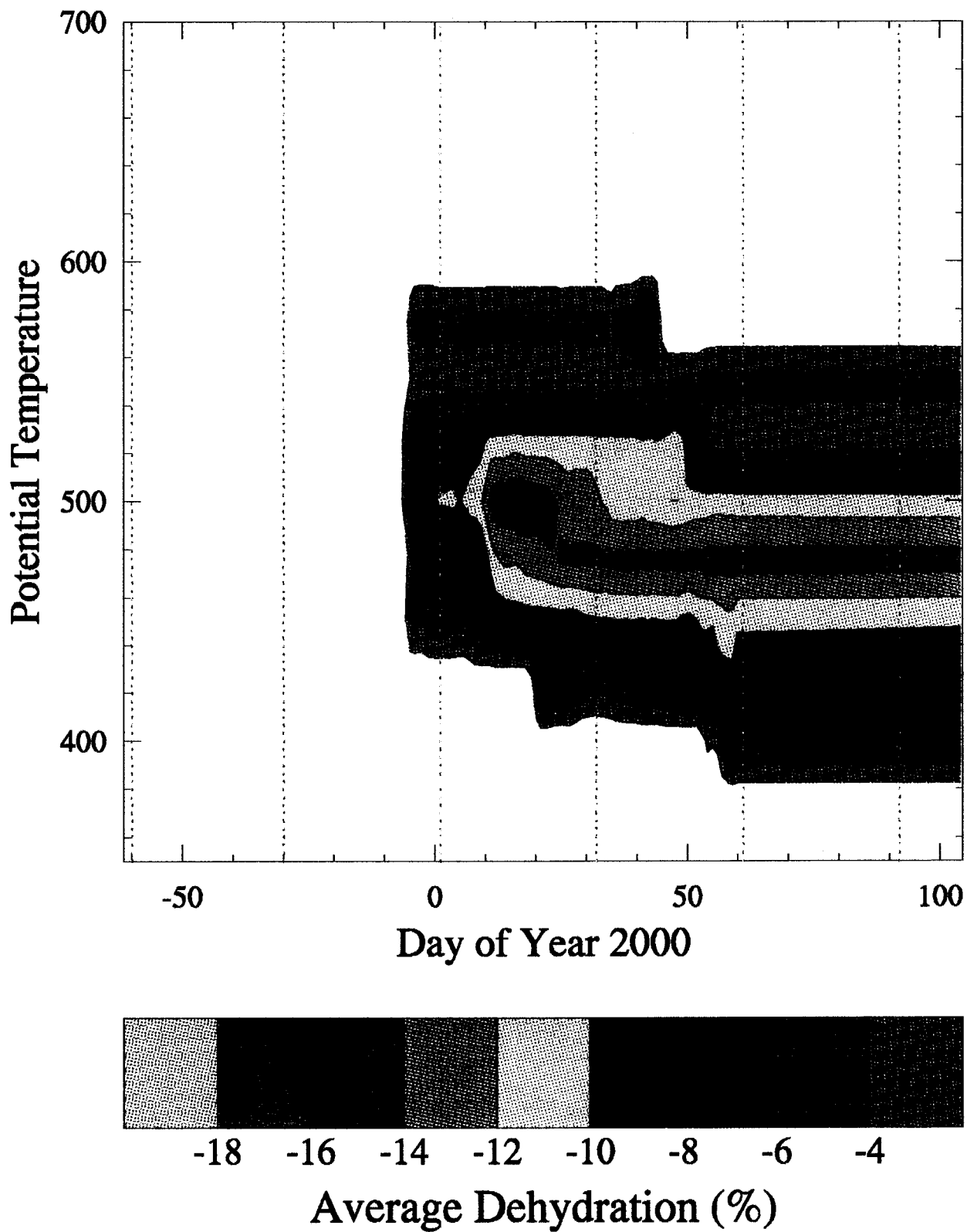
# Evolution of 1999-2000 Arctic Winter Dehydration



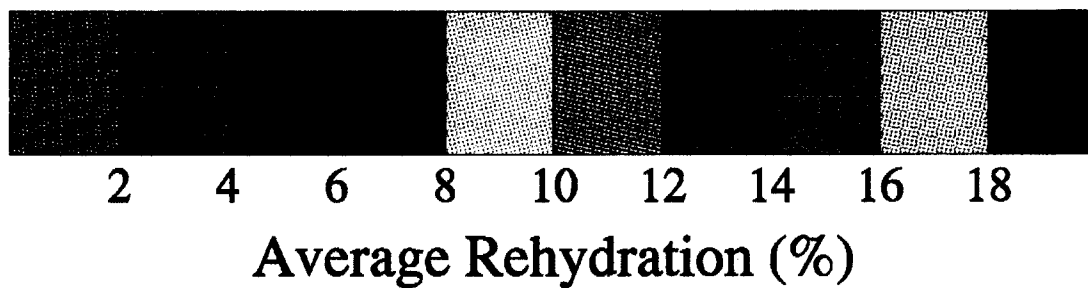
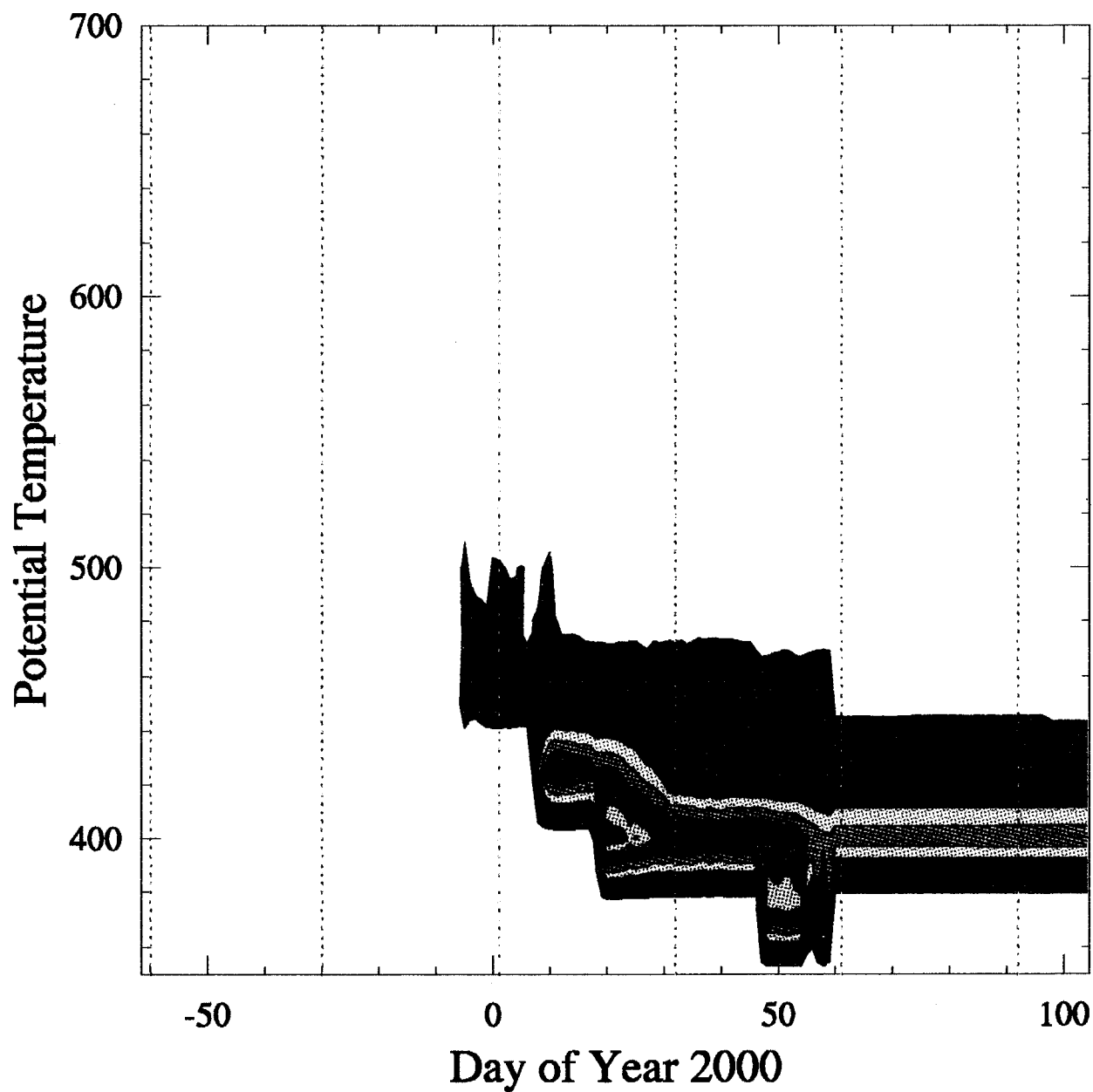
# Evolution of 1999-2000 Arctic Winter Maximum Dehydration



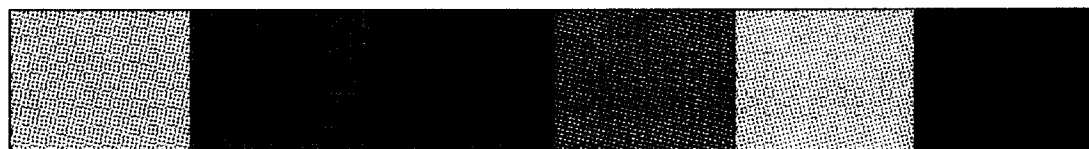
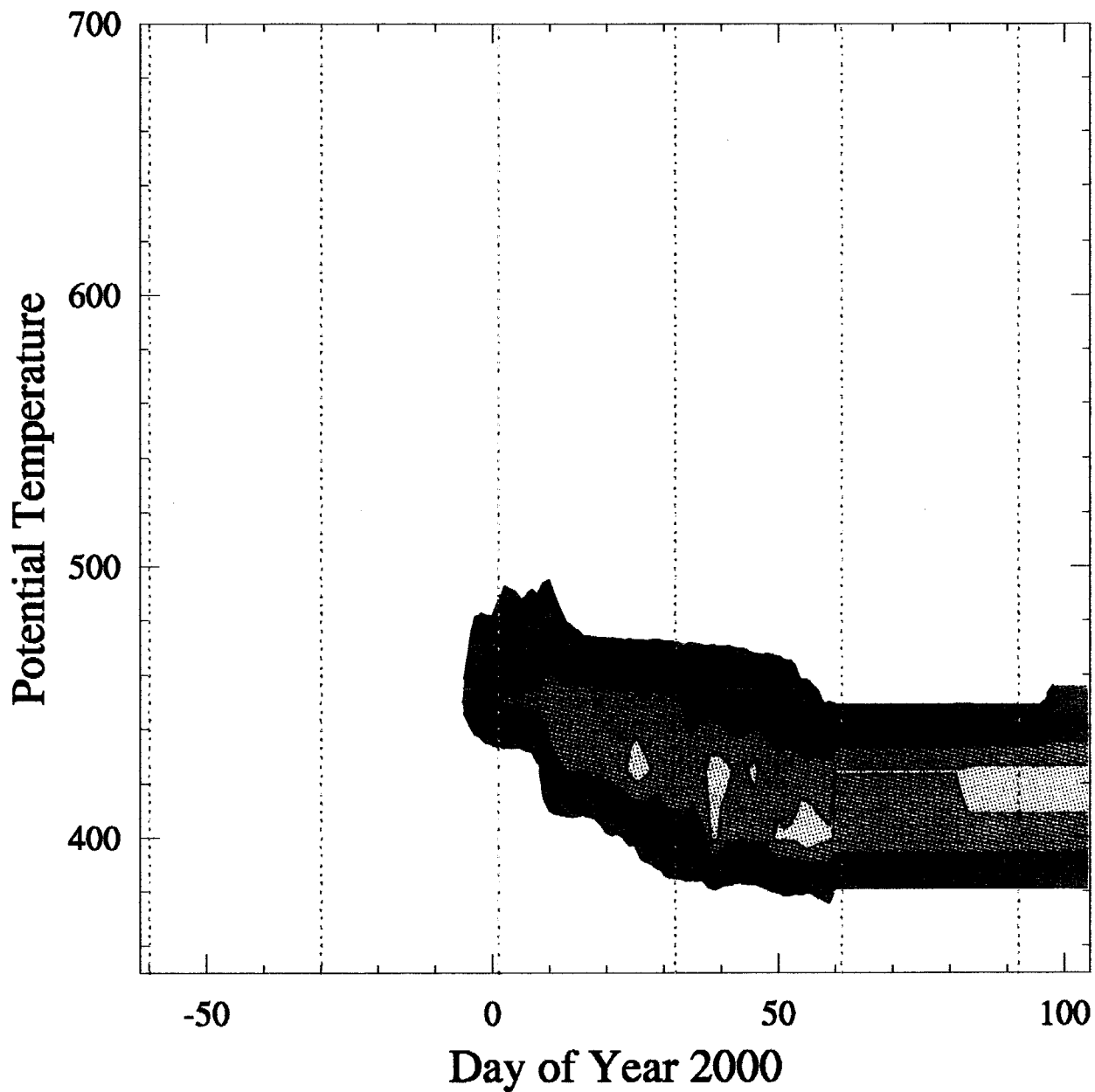
# Evolution of 1999-2000 Arctic Winter Dehydration in Parcels with H<sub>2</sub>O Loss



# Evolution of 1999-2000 Arctic Winter Rehydration in Parcels with H<sub>2</sub>O Gain

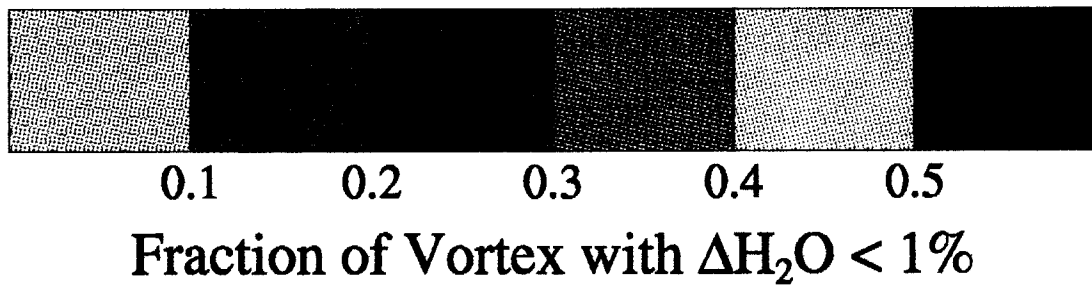
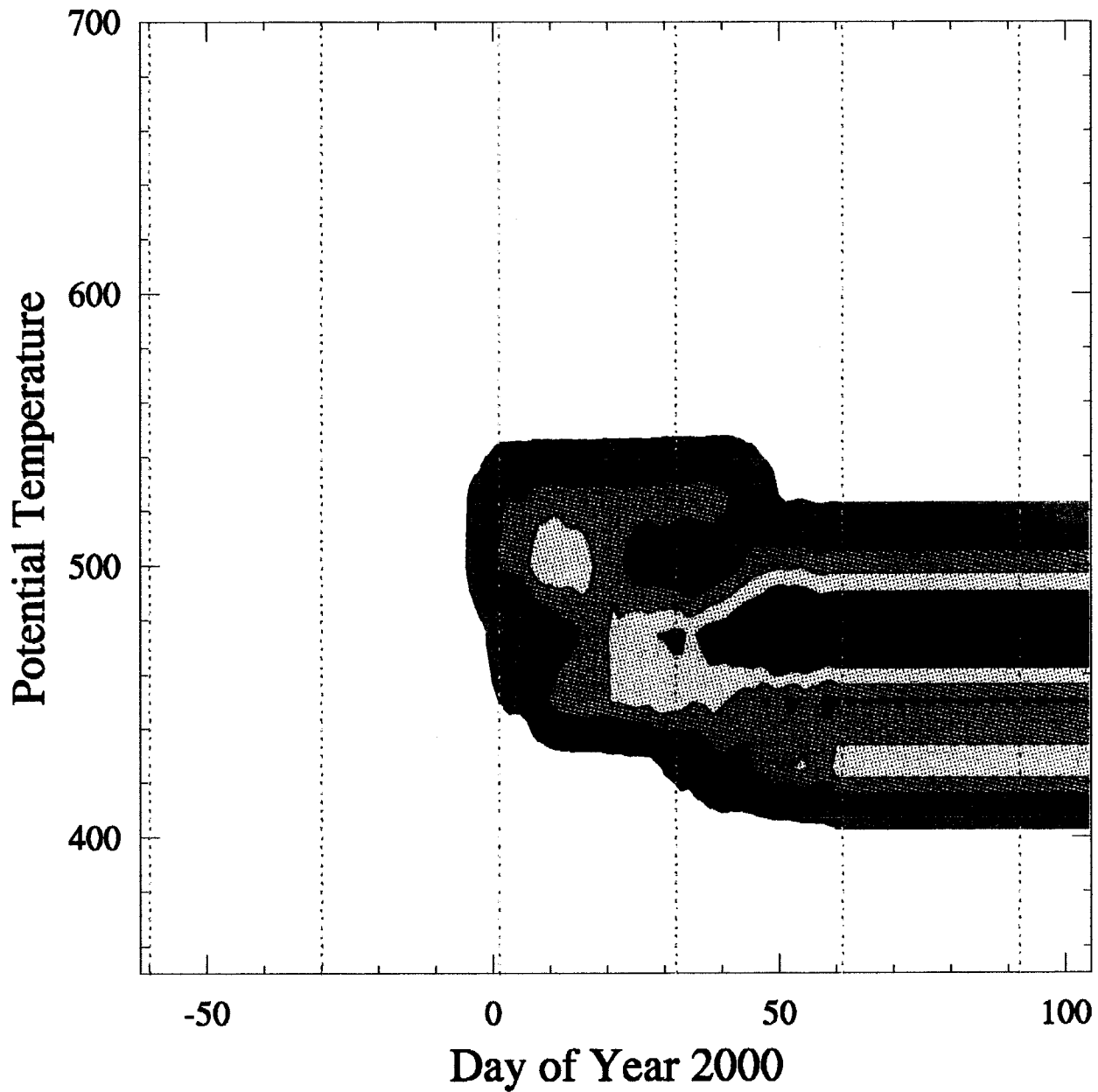


# Evolution of 1999-2000 Arctic Winter Fraction of Vortex with H<sub>2</sub>O Gain



Fraction of Vortex with  $\Delta H_2O > 0.5\%$

# Evolution of 1999-2000 Arctic Winter Fraction of Vortex with H<sub>2</sub>O Loss



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